On Using MOSEK to Solve

Large-Scale Linear and Conic Optimization Problems

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MOSEK ApS

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Some facts

About MOSEK:

- Software package for solving optimization problems.
- Version 1 released 1999.
- Version 7 released 2013.

Problem types:

- Linear + integer variables.
- Conic quadratic + integer variables.
- Semidefinite optimization.
- Convex quadratic + integer variables.
- General convex.

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The system

Several interfaces:

- Fusion API, Optimizer API and toolbox.
- Supports different languages and tools.

One optimization engine:

- Written C.
- Tuned for the large-scale sparse case.
- Exploit hardware features such as AVX instructions.

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Optimizers for continuous problems

Optimizer	Problem type: Network	Linear	Conic	Convex
Network simplex	+			
Primal simplex	+	+		
Dual simplex	+	+		
Interior-point	+	+	+	+

Simplex optimizers

- Large-scale sparse.
- Many options for pricing etc.

Interior-point

- Large-scale sparse with tuned linear algebra.
- Parallelized.
- Reliable infeasibility detection and reporting.

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Optimizers for mixed-integer problems

Mixed integer conic

- Solves mixed-integer linear and conic quadratic problems.
- Parallelized.
- Run-to-run deterministic.
- Tuned for conic quadratic problems.
- No additional charge.

Mixed integer optimizer

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Supported platforms and tools

Supported platforms operating systems

Windows,MAC OSX, Linux

MOSEK interfaces

AMPL, C/C++, Java, Python, Matlab, Microsoft .NET, R

Third party products

AIMMS, GAMS, Frontline Solver, CVX, Woodstock

Other interfaces

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Installation

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Portfolio optimization in Python Fusion

Portfolio optimization in MATLAB

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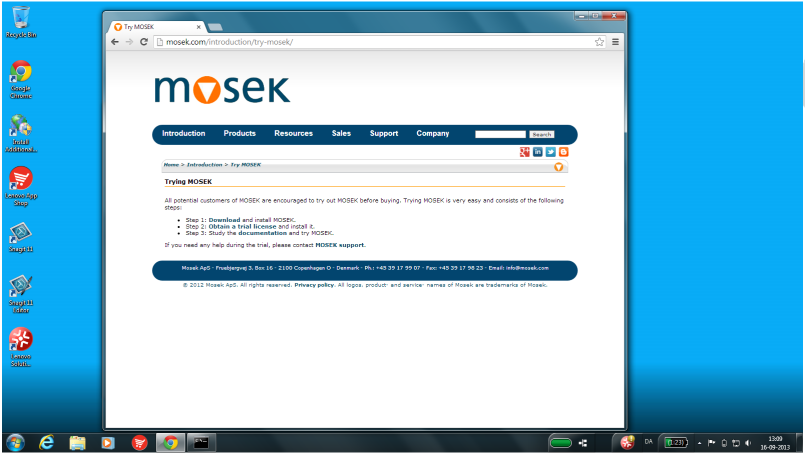
Try MOSEK



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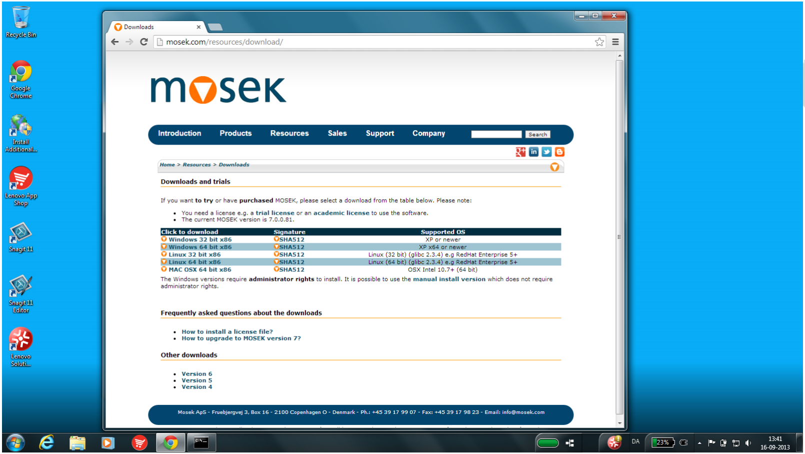

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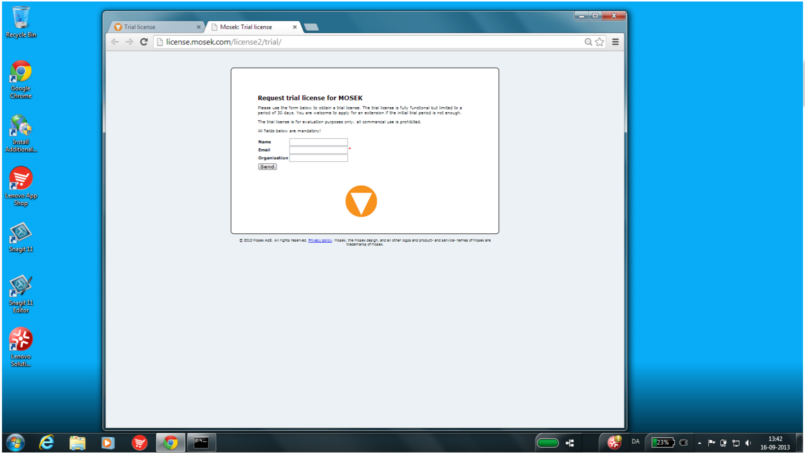

Portfolio optimization

Markowitz portfolio optimization

- Find the optimal portfolio of assets.
- A one period model.
- Invented by H. Markowitz.
- Used extensively by hedge funds and investment companies.

The model

Markowitz model:

$$
\begin{array}{ll}
\text{maximize} & r^T x - \alpha s \\
\text{subject to} & \sum_i x_i = 1 \\
 & (s, Gx) \in \mathcal{Q}^n \\
 & x \geq 0,
\end{array}
$$

with r: average return, $G^T G$: correlation, α: risk-aversion.

- $(s, Gx) \in \mathcal{Q}^n \quad \Leftrightarrow \quad s \geq ||Gx||.$
- s is the std. dev. of the return i.e. risk.
- Optimize a weighted combination of return and risk.
- In practice solved for many values of α.

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A MOSEK Fusion implementation

What is Fusion?

- An object orientated interface for building linear and conic optimization models.
- Works directly with variables and constraints.
- Easy to build and modify a model.
- Available for Java, MATLAB, .NET and Python.
- Models are similar in all languages.

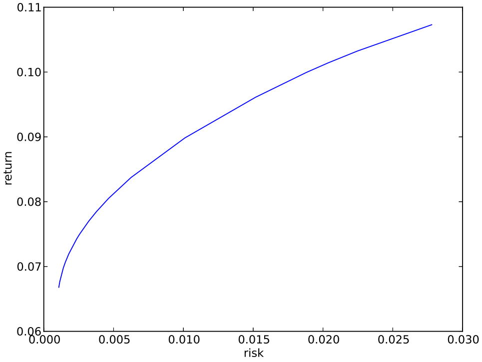
Portfolio example in Python Fusion:

```python
from mosek.fusion import *

def dot(x,y):
    r = 0.0
    for j in range(len(x)):
        r = r+x[j]*y[j]
    return r

def EfficientFrontier(r,G,alphas):
    n = len(r)

    M = Model('Efficient frontier')
    x = M.variable('x', n, Domain.greaterThan(0.0)) # Portfolio variables
    s = M.variable('s', 1, Domain.unbounded())      # Risk variable
    M.constraint('budget', Expr.sum(x), Domain.equalsTo(1.0))                     # sum(x) = 1
    M.constraint('risk',   Expr.vstack(s, Expr.mul(G,x)), Domain.inQCone())    # norm(Gx) <= s

    frontier = []
    for a in alphas:
       #  objective:  r'*x - a*s
       M.objective('obj', ObjectiveSense.Maximize, Expr.sub(Expr.dot(r,x), Expr.mul(a,s)))
       M.solve()
       frontier.append( (a, dot(r,x.level()), s.level()[0]) )

    return frontier

if __name__ == '__main__':

    r =   [ 0.1073,  0.0737,  0.0627 ]      # Vector of average returns
    G = [ [ 0.1667,  0.0232,  0.0013 ],     # Cholesky Factor of Sigma.
          [ 0.0000,  0.1033, -0.0022 ],
          [ 0.0000,  0.0000,  0.0338 ] ]

    alphas   = [0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 10.0]
    frontier = EfficientFrontier(r,DenseMatrix(G),alphas)

    print('\nEfficient frontier')
    print('%-12s  %-12s  %-12s' % ('alpha','return','risk'))
    for i in frontier:
        print('%-12.4f  %-12.4e  %-12.4e' % (i[0],i[1],i[2]))
```

Portfolio optimization

Efficient Frontier

The *efficient frontier* shows the optimal trade-off.



Fusion summary

- Java, MATLAB and .NET Fusion looks almost identical.
- Model is close to the paper version.
- Excellent for rapid linear and conic model building.

MATLAB toolbox implementation

MATLAB

- MATLAB is a high-level language and interactive environment for numerical work.
- Popular among engineers, in finance, everywhere

MOSEK optimization toolbox for MATLAB includes

- A matrix orientated interface.
- Lower level than Fusion.
- linprog, quadprog, etc clones.

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Serializing the model

First reformulation:

$$
\begin{array}{ll}
\text{maximize} & r^T x - \alpha s \\
\text{subject to} & e^T x = 1 \\
 & Gx - t = 0 \\
 & (s, t) \in \mathcal{Q}^n \\
 & x \geq 0,
\end{array}
$$

where

$$e = [1, \ldots, 1]^T.$$

A new variable:

$$\bar{x} = \begin{bmatrix} x \\ t \\ s \end{bmatrix} = [x; t; s]$$

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cont.

Next reformulation

$$
\begin{array}{ll}
\text{maximize} & \begin{bmatrix} r^T & 0_{1\times n} & -\alpha \end{bmatrix} \bar{x} \\
\text{subject to} & \begin{bmatrix} e_{1\times n} & 0_{1\times n} & 0 \end{bmatrix} \bar{x} = 1 \\
& \begin{bmatrix} G & -I_{n\times n} & 0_{n\times 1} \end{bmatrix} \bar{x} = 0 \\
& \bar{x}_{2n+1} \geq ||\bar{x}_{(n+1):(2n)}|| \\
& \bar{x}_{1:n} \geq 0,
\end{array}
$$

MOSEK model

$$
\begin{array}{ll}
\text{maximize} & c^T x \\
\text{subject to} & l^c \leq Ax \leq u^c \\
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cont.

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Portfolio example in MATLAB:

```
[ret, res] = mosekopt('symbcon echo(0)');

r          = [ 0.1073,  0.0737,  0.0627 ]';
G          = [ [ 0.1667,  0.0232,  0.0013 ];...
               [ 0.0000,  0.1033, -0.0022 ];...
               [ 0.0000,  0.0000,  0.0338 ] ];
alphas     = [0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 10.0];
n          = length(r);

clear prob;

% The the problem.
prob.a            = [[ones(1,n),zeros(1,n),0];...
                     [G,-speye(n),zeros(n,1)]];
prob.blc          = [1;zeros(n,1)];
prob.buc          = [1;zeros(n,1)];
prob.blx          = [zeros(n,1);-inf*ones(n+1,1)];

prob.cones.type   = [res.symbcon.MSK_CT_QUAD];
prob.cones.sub    = [(2*n+1),(n+1):(2*n)];
prob.cones.subptr = [1];

% Compute the efficient frontier.
for i=1:length(alphas)
    alpha               = alphas(i);
    prob.c              = [r;zeros(n,1);-alpha];
    [ret,res]           = mosekopt('maximize echo(0)',prob);
    x                   = res.sol.itr.xx;
    fprintf('%.2e %.4e %.4e\n',alpha,r'*x(1:n),x(2*n+1));
end
```

MATLAB run

```
>> portfolio
alpha        ret          risk
0.00e+00     1.0730e-01   7.2173e-01
1.00e-01     1.0730e-01   1.6670e-01
2.00e-01     1.0730e-01   1.6670e-01
3.00e-01     8.0540e-02   6.8220e-02
4.00e-01     7.1951e-02   4.2329e-02
5.00e-01     6.9756e-02   3.7355e-02
7.50e-01     6.7660e-02   3.3827e-02
1.00e+00     6.6790e-02   3.2811e-02
1.50e+00     6.5984e-02   3.2139e-02
2.00e+00     6.5601e-02   3.1916e-02
3.00e+00     6.5221e-02   3.1758e-02
1.00e+01     6.4698e-02   3.1645e-02
```

MATLAB summary

- Matrix orientated input.
- Models must be serialized.
- Can be used to replace linprog and friends.
- Similar interface is available for R.

Using the optimizer API

API model:

$$
\begin{array}{ll}
\text{maximize} & c^T x \\
\text{subject to} & l^c \leq Ax \leq u^c \\
 & x \in K \\
 & l^x \leq x \leq u^x
\end{array}
$$

- Serialized view. One variable only.
- Use function calls to input data.

MATLAB example thinking reuse

Problem

$$
\begin{array}{ll}
\text{maximize} & \left[\begin{array}{ccc} r^T & 0_{1\times n} & -\alpha \end{array}\right] \bar{x} \\
\text{subject to} & \left[\begin{array}{ccc} e_{1\times n} & 0_{1\times n} & 0 \end{array}\right] \bar{x} = 1 \\
& \left[\begin{array}{ccc} G & -I_{n\times n} & 0_{n\times 1} \end{array}\right] \bar{x} = 0 \\
& \bar{x}_{2n+1} \geq ||\bar{x}_{(n+1):(2n)}|| \\
& \bar{x}_{1:n} \geq 0,
\end{array}
$$

```c
#include <math.h>
#include <stdio.h>

#include "mosek.h"

#define MOSEKCALL(_r,_call)  ( (_r)==MSK_RES_OK ? ( (_r) = (_call) ) : ( (_r) = (_r) ) );


static void MSKAPI printstr(void *handle,
                            MSKCONST char str[])
{
  printf("%s",str);
} /* printstr */


int main(int argc, const char  argv[])
{
  const MSKint32t n=3,numalpha=12;
  const double    r[]={0.1073,  0.0737,  0.0627},
                  G[][3]={{0.1667,  0.0232,  0.0013},
                          {0.0000,  0.1033, -0.0022},
                          {0.0000,  0.0000,  0.0338}},
                  alphas[12]={0.0, 0.1, 0.2, 0.3, 0.4, 0.5,
                              0.75, 1.0, 1.5, 2.0, 3.0, 10.0};
  MSKenv_t        env;
  MSKint32t       k,i,j,*sub;
  MSKrescodee     res=MSK_RES_OK;
  MSKtask_t       task;

  sub = calloc(n,sizeof(MSKint32t));

  res = sub==NULL ? MSK_RES_ERR_SPACE : MSK_RES_OK;
```

```c
MOSEKCALL(res,MSK_makeenv(&env,NULL));
MOSEKCALL(res,MSK_maketask(env,0,0,&task));
MOSEKCALL(res,MSK_linkfunctotaskstream(task,MSK_STREAM_LOG,NULL,printstr));

/* Constraints. */
MOSEKCALL(res,MSK_appendcons(task,1+n));
MOSEKCALL(res,MSK_putconbound(task,0,MSK_BK_FX,1.0,1.0));
for(i=0; i<n; ++i)
  MOSEKCALL(res,MSK_putconbound(task,1+i,MSK_BK_FX,0.0,0.0));

/* Variables. */
MOSEKCALL(res,MSK_appendvars(task,1+2*n));
/* x variables. */
for(j=0; j<n; ++j)
{
  MOSEKCALL(res,MSK_putcj(task,j,r[j]));
  MOSEKCALL(res,MSK_putaij(task,0,j,1.0));
  for(k=0; k<n; ++k)
    MOSEKCALL(res,MSK_putaij(task,1+k,j,G[k][j]));

  MOSEKCALL(res,MSK_putvarbound(task,j,MSK_BK_LO,0.0,MSK_INFINITY));
}
```

```
/* t variables. */
for(j=0; j<n; ++j)
{
  MOSEKCALL(res,MSK_putaij(task,1+j,n+j,-1.0));
  MOSEKCALL(res,MSK_putvarbound(task,n+j,MSK_BK_FR,-MSK_INFINITY,MSK_INFINITY));
}

/* s variable. */
MOSEKCALL(res,MSK_putvarbound(task,2*n,MSK_BK_FR,-MSK_INFINITY,MSK_INFINITY));

sub[0] = 2*n;
for(j=0; j<n; ++j)
  sub[j+1] = n+j;
MOSEKCALL(res,MSK_appendcone(task,MSK_CT_QUAD,0.0,n+1,sub));

MOSEKCALL(res,MSK_putobjsense(task,MSK_OBJECTIVE_SENSE_MAXIMIZE));
MOSEKCALL(res,MSK_putintparam(task,MSK_IPAR_LOG,0));
```

```c
  for(k=0; k<numalpha; ++k)
  {
    MOSEKCALL(res,MSK_putcj(task,2*n,-alphas[k]));

    /* MOSEKCALL(res,MSK_writedata(task,"dump.opf")); */

    MOSEKCALL(res,MSK_optimize(task));

    /* MSK_solutionsummary(task,MSK_STREAM_MSG); */

    if ( res==MSK_RES_OK )
    {
      double er=0.0,xj;

      for(j=0; j<n; ++j)
      {
              MOSEKCALL(res,MSK_getxxslice(task,MSK_SOL_ITR,j,j+1,&xj));
              er += r[j]*xj;
      }

      MOSEKCALL(res,MSK_getxxslice(task,MSK_SOL_ITR,2*n,2*n+1,&xj));

      printf("%e %e %e\n",alphas[k],er,xj);
    }
  }

  free(sub);

  return ( 0 );
}
```

Building instructions

Using Visual studio command line tools:

```
cl portfolio.c
   /I "\program files\mosek\7\tools\platform\win64x86\h"
   /link "\program files\mosek\7\tools\platform\win64x86\bin\mosek64_7_0.lib"
```

on one line.

Running:

```
portfolio
0.000000e+000 1.073000e-001 7.217338e-001
1.000000e-001 1.073000e-001 1.667000e-001
2.000000e-001 1.073000e-001 1.667000e-001
3.000000e-001 8.053969e-002 6.822048e-002
4.000000e-001 7.195059e-002 4.232918e-002
5.000000e-001 6.975570e-002 3.735526e-002
7.500000e-001 6.766020e-002 3.382745e-002
1.000000e+000 6.679036e-002 3.281117e-002
1.500000e+000 6.598434e-002 3.213941e-002
2.000000e+000 6.560097e-002 3.191621e-002
3.000000e+000 6.522112e-002 3.175819e-002
1.000000e+001 6.469785e-002 3.164510e-002
```

Debugging tips

Use writedata:

```
MSK_writedata(task,"dump.opf");
```

Content of dump.opf:

```
[objective maximize]
   1.073e-001 x0000 + 7.37e-002 x0001 + 6.270000000000001e-002 x0002 - 1e+001 x0006
[/objective]

[constraints]
  [con c0000]  x0000 + x0001 + x0002 = 1e+000 [/con]
  [con c0001]  1.667e-001 x0000 + 2.32e-002 x0001 + 1.3e-003 x0002 - x0003 = 0e+000 [/con]
  [con c0002]  1.033e-001 x0001 - 2.2e-003 x0002 - x0004 = 0e+000 [/con]
  [con c0003]  3.38e-002 x0002 - x0005 = 0e+000 [/con]
[/constraints]

[bounds]
  [b]          0 <= * [/b]
  [b]               x0003,x0004,x0005,x0006 free [/b]
  [cone quad k0000] x0006, x0003, x0004, x0005 [/cone]
[/bounds]
```

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[constraints]
  [con c0000]  x0000 + x0001 + x0002 = 1e+000 [/con]
  [con c0001]  1.667e-001 x0000 + 2.32e-002 x0001 + 1.3e-003 x0002 - x0003 = 0e+000 [/con]
  [con c0002]  1.033e-001 x0001 - 2.2e-003 x0002 - x0004 = 0e+000 [/con]
  [con c0003]  3.38e-002 x0002 - x0005 = 0e+000 [/con]
[/constraints]

[bounds]
  [b]          0 <= * [/b]
  [b]               x0003,x0004,x0005,x0006 free [/b]
  [cone quad k0000] x0006, x0003, x0004, x0005 [/cone]
[/bounds]
```

Tuning tips

Reduce looping:

Use

```
MSK_putcslice(task,0,n,r);
```

instead of

```
for(j=0; j<n; ++j)
  MSK_putcj(task,j,r[j]);
```

Optimizer API summary

- Harder to code against the optimizer API than the Fusion API.
- Highly efficient. Particularly for change and reoptimize.
- Optimizer API available for Java, .NET and Python too.

Summary

MOSEK features:

- Powerful optimization engine.
- Many interfaces included.
- Extensive documentation available.
- Fusion API is easier to use than optimizer API.

Slides!

- http://mosek.com/resources/presentations/

Summary

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